Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 40 (2016) 705 – 710

www.elsevier.com/locate/procedia

13th Global Conference on Sustainable Manufacturing - Decoupling Growth from Resource Use

The development of compressor noise barrier in the assembly area (Case study of PT Jawa Furni Lestari)

Nur Indrianti*, Nandyan Banyu Biru, and Tri Wibawa

Industrial Engineering Department, Universitas Pembangunan Nasional "Veteran" Yogyakarta, Jl. SWK 104 (Lingkar Utara), Condongcatur, Yogyakarta 55283, Indonesia

* Corresponding author. Tel.: +62-274-486733; fax: +62-274-486400. *E-mail address:* n.indrianti@upnyk.ac.id

Abstract

This study deals with noise problem at the Indonesian teak wood furniture manufacturing company called PT Jawa Furni Lestari. The noise is generated by air compressor which is used for dyeing and spraying processes in the assembly area. The highest noise intensity indicates the value of 106.28 dB, which passes the threshold value i.e. 85 dB. The aim of this study is to reduce the noise level by constructing noise barrier. We used Pahl and Beitz approach for the barrier development process and modified idle space under the stairs in the assembly area. Consequently the compressor must be relocated from its present location. The result of the study shows that the construction of the barrier could reduce noise by 32.29 dB. In addition to reducing noise due to barrier construction, compressor relocation provides larger area for production activities. The evaluation result shows that the operators in the assembly area are very satisfied with the condition after the barrier is constructed.

Peer-review under responsibility of the International Scientific Committee of the 13th Global Conference on Sustainable Manufacturing

Keywords: noise; air compressor; noise barrier; Pahl and Beitz.

1. Introduction

Production processes in industry cannot be separated from technology which is supported by machines. However, if the machines are not well maintained it will cause hazardous noise.

Hazardous noise affects human ability to hear high-frequency sounds. It means that even though a person can still hear sounds, conversation will start to sound 'muffled' and a person may find it difficult to understand what is being said [1]. Such condition may disrupt communication process in working atmosphere that may affect employee performance. In terms of cooperation, instruction delivery as well as the delivery of the message will be severely impaired. It may result in disruption of work process and increased risk of workplace accidents due to the possibility of misunderstandings among fellow workers when there is an emergency situation.

"Noise is unwanted sound from activity in certain rate and time, which can cause human health problems and environmental comfort" [2]. Sound waves originate from the vibration of some object, which in turns set up a succession of compression and expansion waves through the transporting medium (air, water, and so on) [3]. In industry the source of sound can be a combination of several components such as fluid turbulence, moving and vibration part, and temperature difference [4]. Moving and vibration part is the source of noise that occurs by the vibration caused by friction, impact or imbalance in the movement of the machinery/equipment such as bearing compressors, turbines, pumps, and blowers [5].

Noise generated by air compressor becomes a problem in PT Jawa Furni Lestari, a manufacturing company located in the village of Krapyak, southern district of Klaten, Central Java, Indonesia. The company produces 20 to 30 units of exported wood furniture a day including wooden shelves, tables, and cabinets. The furniture is made of teak wood supplied by a company that has been certified by the Indonesian Ecolabelling Institute.

PT Jawa Furni Lestari uses an air compressor for dyeing and spraying processes. The dimension of the compressor is 1.74 m length, 75 cm width, and 1.20 m height. The compressor is operated using electricity with 8 bar of wind

Peer-review under responsibility of the International Scientific Committee of the 13th Global Conference on Sustainable Manufacturing
doi:10.1016/j.procir.2016.01.158

pressure, 1190 rpm of engine speed, and 7.5 HP or 5.5 MW of power. The compressor is currently located in the assembly area surrounded by several rafts and other production machines. In fact, the compressor causes high noise around the production area.

The highest noise intensity resulted by the compressor indicates the value of 106.28 dB, which passes the threshold value regulated by the Minister of Manpower, Transmigration, and Cooperatives of the Republic of Indonesia, i.e. 85 dB [6]. The threshold value is considered safe for most workers if they work 8 hours a day or 40 hours a week, but not fully guarantee that workers would not exposed to risks due to noise but only reduce existing risks. If the noise in the assembly area of PT Jawa Furni Lestari happens constantly, it will be harmful to the health of the employee hearing. Moreover, the personal protection equipment is not currently used in the company. Therefore, lowering the noise level below the threshold value is necessary.

This study aims to reduce noise level in the production area of PT Jawa Furni Lestari. To solve the problem, we proposed to create sound barrier for the compressor machine. We used Pahl and Beitz procedure to develop the barrier. As an alternative for the barrier we modified idle space under the stairs in the assembly area. Consequently, the compressor should be relocated from the production area to the modified space. This compressor relocation is expected to give a positive impact especially in providing a larger space for production activities.

2. Literature review

2.1. Pahl and Beitz product development model

Product development is a series of activities starting from the analysis of perception and opportunities. One of the approaches for product development is proposed by Pahl and Beitz which consists of four-phase design procedure [7]. The first phase is task planning. This phase aims to generate a list of requirements and design specifications.

The second phase of Pahl and Beitz procedure is product concept design. This phase is intended to prepare special functions and certain characteristics that meet the needs of the community by combining several different possibilities. Alternatives evaluation is done based on technical and economic criteria. This phase results in design concept.

The concept resulted from the second phase is then developed in the third phase and results in an embodiment design. This is then further developed to be detailed design in the fourth phase which defines the arrangement of the components, the shape, dimensions, surface smoothness and material of each component. Likewise, the possibility of production process is analyzed and the production cost is estimated. The final result of this phase is complete design drawings and specifications for the manufacture of products.

2.2. Noise barrier

Barriers are commonly used as a method of abating noise. It isolates the source of noise from people. Noise barrier is an exterior structure that is designed to dampen the noise. It is the most effective method of reducing road, rail, and industrial noise sources without halt the use of source control [8].

There are some factors to consider when designing and constructing barriers. They include barrier position, layout, shape, material density, and dimensions [9].

Maekawa method is theoretically known as an efficient method in the design of noise barriers using acoustic barrier. This method provides the ease and certainty to the designer to control the noise. In this case, the value of the sound pressure level reduction depends on the distance from the sound source to the barrier, barrier dimension, and the frequency of the sound resulted from the source [10].

There have been several studies about noise reduction. A study on the dangers of noise in cement plants on human health proposed system and control stages that were based on the comprehensive theory of voice control such as noise attenuation, absorption, and isolation as well as measures of management and technology [11]. Another study was about a natural ventilation to measure the interaction of noise exposure [12]. In this study an open vent was constructed to serves as a sound absorber in naturally ventilated buildings. This method is used to consider potential vents at different locations.

In terms of noise barrier performance, there has been a discussion on the effects of the ground, sound absorbing material, barrier shapes, the type of barrier (series or parallel), and the atmosphere [13]. An efficient prediction model has been proposed based on the simulation of the sound wave propagation in case of noise barrier. The model was validated using Maekawa's method and more accurate prediction method such as Kurze-Anderson's model [14].

2.3. Noise measurement

The *decibel* (dB) has been chosen as the unit of sound intensity and measured using a sound-level meter [3]. The sound level meter measures noise between 30-130 dB and of frequencies ranging from 20 to 2000 Hz. The working mechanism of sound level meter is when an object vibrates there will be a change in air pressure that can be captured by this tool, which in turn will drive the meter instruction.

Noise measurement can be done by calculating noise at several points around the most severe affected area. Since sound pressure levels are logarithmic quantities, the total noise can be calculated as follows [3]:

$$TL_{Overall} = 10 \log \left(\sum_1^n 10^{0,1L_n}\right) \quad (1)$$

The noise levels at several noise sources where workers are exposed are then used as a reference for the preparation of noise maps. This method is very useful because map image can determine the condition of noise in the coverage area.

Noise mapping can be done by drawing the layout of the coverage area using paper scale. It is created by colour code to describe the state of noisy. Green colour is for the noise less than 84 dB, yellow for high noise level between 85-95 dB, and red for noise level of more than 95 dB. Noise maps can also be created using Surfer 8 software [9].

2.4. Noise reduction of barrier

Theoretical sound power level is defined as noise level generated by the sound of the machine. It can be calculated using the following equation [15]:

$$L_W = 84+10\ \log_{10}MW+6.6\ \log_{10}RPM \qquad (2)$$

Noise reduction of barrier can be determined taking into account the materials that are used to construct the barrier. It is calculated as follows:

$$TL_{barrier} = NR_{Plan} - 10\log\left(\frac{A\ total}{S\ total}\right) \qquad (3)$$

$$NR = TL_{Barrier} + 6\ \text{dB} \qquad (4)$$

3. Results and discussion

3.1. Noise barrier development

Noise level at the initial condition was measured using sound-level meter based on 15 points in the assembly area. Each point was measured based on six frequencies, i.e. 125, 250, 500, 1000, 2000, and 4000 Hertz. Thus, there were 90 samples. The result of the measurement is shown in Table 1.

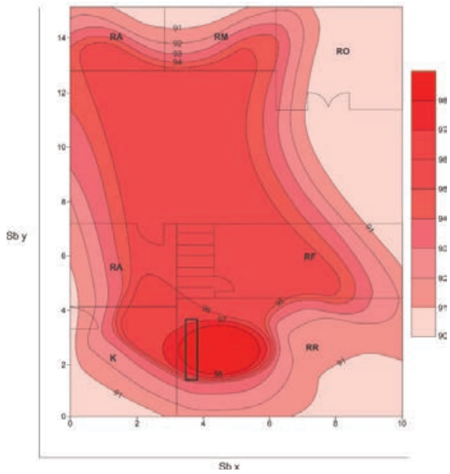
Table 1. Initial noise level

Point	Noise level (dB)	Point	Noise level (dB)	Point	Noise level (dB)
1	98.0	6	97.6	11	96.8
2	94.3	7	92.2	12	95.0
3	91.5	8	95.2	13	93.5
4	92.4	9	95.4	14	95.4
5	92.8	10	93.0	15	92.5

Assuming 0.1 of the true proportion, 0.95 confidence level, and 0.05 maximum error allowed, the minimum required sample size is 21.7 [16]. Thus, 90 samples are enough.

The overall noise level was calculated using Equation (1) and noise map was created using software Surfer 8. We obtained initial noise level of 106.28 dB. The noise map can be seen in Figure 1 in which the location of the compressor is marked with rectangle.

Theoretical sound power level of the compressor can be calculated using Equation (2). With 1190 rpm of engine speed and 5.5 MW of engine power, it obtains 116.5 dB of sound level.



RA: sand-papering room; RM: machine room; K: office; RF: finishing rrom; RR: assembly room; RO: oven room.

Fig. 1. Initial noise map of assembly area

To develop noise barrier, firstly we identified functions and determined components and criteria to achieve the functions. This step was done using questionnaire distributed to the head of the plant, the head of the field, and craftsman. The results are as follows:

- Design
  - Shape and models: ergonomic, easy to open, and saving space
  - Color: not too flashy, easily to find, and adapted to the selected material
- Material
  - Lifetime: 4-8 years
  - Weight: customized with selected material
  - Wall and door coating: easy to install, thicker than 6 mm
- Functions
  - Space expansion: inside the plant

We then determined the criteria of each function. The result is shown in Table 2.

Table 2. Functions and criteria

Func-tions	Description	Criteria
F1	Door material	Strong, lightweight, and easy to install
F2	Color	Customized with selected materials
F3	Life time	4-8 years
F4	Door outer coating	Non-flammable, easy to install, thick, and easy to find
F5	Door second coating	Thicker than 6 mm and easy to find
F6	Door third coating	Thick enough and has a specificity as absorbers
F7	Door model	Minimalist, easy to open, and saving space
F8	Wall coating material	Easy to install and thick
F9	The shape of the front wall vents	Easy to manufacture and facilitates air circulation
F10	Place	Easy to realize the design and easy to move the compressor and wiring

The next step was generating design alternatives for the barrier. The result is shown in Table 3.

Table 3. Design alternatives

Func-tions	Design alternatives		
	1	2	3
F1	iron	wood	aluminum
F2	black	brown	grey
F3	<7 years	4-8 years	6 years
F4	plywood	kalsibot	styrofoam
F5	plywood	glass wool/dacron	gypsum
F6	standard carpet, thickness of 3 mm	Kalsibot, glass wool and apollo carpet	standard carpet, thickness of 4 mm
F7	two doors	sliding door	one door
F8	standard carpet and wood	kalsibot, glass wool, and apollo carpet	carpet and styrofoam
F9	oval	rectangular	square
F10	an area inside plan which allows the displacement of the compressor and the cord	paddy field outside the assembly area	empty space under the stairs in the assembly area

Figure 2 shows three types of carpet that are considered as dampening materials. The thickness of dampening carpet, plywood, and glass wool are 7 mm, 15 mm, and 5 mm respectively. The thickness of the materials is in accordance with the common size which is easy to find on the market.

The door frame is made of wood and covered with plywood with a thickness of 15 mm. The thick plywood was selected because it is heat resistant, ergonomic, and does not crack during the process of installation.

Fig. 2. (a) dampening carpet; (b) *glasswool;* (c) apollo carpet

The evaluation of the alternatives was done using questionnaire to 15 operators who work around the air compressor. The result is shown in Table 4.

Table 4. Alternatives evaluation

Func-tions	Number of respondents			Decisions
	Alt. 1	Alt. 2	Alt. 3	
F1	5	8	2	wood
F2	2	10	3	brown
F3	2	12	1	4-8 years
F4	9	4	*2*	plywood
F5	6	8	1	*glass wool/dacron*
F6	3	11	2	kalsibot, glass wool, and apollo carpet
F7	4	4	7	one door
F8	4	7	4	kalsibot, glass wool, and apollo carpet
F9	3	10	2	rectangular
F10	7	3	5	empty space under the stairs in the assembly area

The dampening layers of the door were structured as follows: plywood, dampening carpet, glass wool, and apollo carpet as the outermost layer. The same composition was used for wall covering, i.e. dampening carpet, glass wool, and apollo carpet as the outermost coating. The wall covering aims to dampen the sound of the compressor so as not to bust out. Figure 3 shows the detailed size of the space under the stairs that was modified as compressor barrier. The total size of the space is 2.25 m^2 with the total surface area including wall is 6.98 m^2.

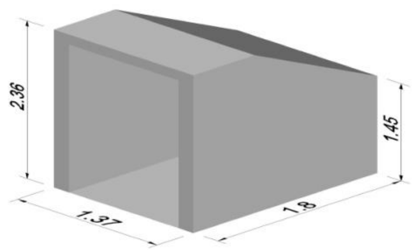


Fig. 3. The shape and size of the space used for the barrier

In order to minimize noise, every stage of the manufacture of door and the installation of barrier coatings was done carefully so that there was no loophole that would make the sound leaking out. Small ventilation, with 20 cm of length and 15 cm of width, was installed on the door roof. After finishing barrier construction, the compressor and all associated equipment such as wiring was moved into the barrier room and set up so that the compressor can work normally as usual.

Noise level after barrier construction was measured based on the same points as the initial measurement with the compressor ran in the barrier room. The way of measuring the noise level was the same as initially done. The sample size test resulted in 33 minimum required samples. So the observed data, i.e. 90 points, is enough.

The calculation result showed that the noise level after barrier construction was 73.99 dB. It means that the installation of barrier could reduce noise by 32.29 dB (from 106.28 dB to 73.99 dB).

Noise map after barrier construction can be seen in Figure 4. The figure shows that the noise level in the assembly area has decreased from the previous conditions and the sound level outside the barrier is below the threshold value (<85 dB). This is because the noise of the compressor engine has been isolated by the barrier.

The transmission loss was calculated using Equation (3) where the total area of the barrier was determined based on the absorption coefficient of the used materials [15]. The calculation obtained 32.67 dB of transmission loss. Based on this transmission loss, the noise reduction was then calculated using Equation (4). It resulted in 36.67 dB of noise reduction.

The cost of compressor barrier was composed of labor and materials costs where the main materials included carpets, plywood, and supplementary materials such as door handle and slot, hinge, and nails. The total cost was IDR 1,525,000.00, which is still acceptable.

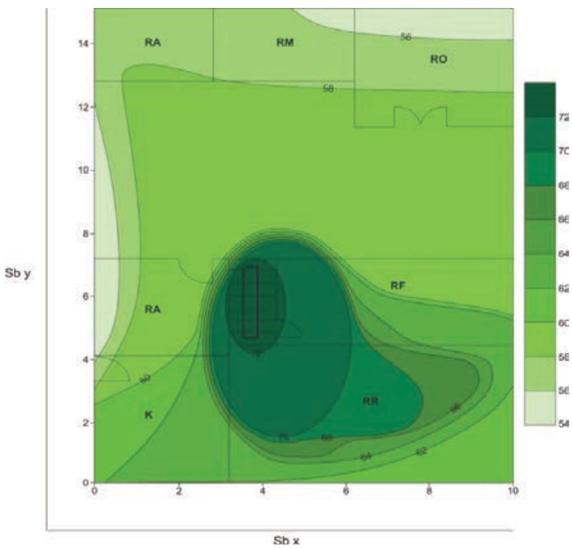


Fig. 4. Noise map after barrier construction

3.2. Discussion

It is shown that barrier construction, which was done by modifying the idle space under the stairs, in the assembly area of PT Jawa Furni Lestari could reduce noise by 32.29 dB, i.e. from 106.28 dB to 73.99 dB. In other words, the constructed barrier could reduce noise level to below the threshold value.

The calculation result shows that the theoretical compressor noise level at the initial condition is 116.5 dB, while physical measurement shows lower value (106.28 dB). The difference of the value may be because of the absorption effect of the atmosphere air.

Physical measurements shows that he constructed barrier could reduce 32.9 dB of noise, while theoretical calculation yielded 36.67 dB of noise reduction. The difference may be because the materials used in this study are not exactly the same as the materials provided in the literature. However, the value difference is still acceptable.

As the consequence of the use of the space under the stairs as a barrier, the compressor was relocated from its present location into the barrier room. Hence, the compressor relocation expands the space for the operators.

Operator satisfaction was investigated using questionnaire to 15 working operators in the assembly area. The questions used a 5 point Likert type scale to measure the response. The results are as follows:

- The construction of the barrier makes the operators feel more comfortable (score: 4.8).
- The construction of the barrier increases the operators' performance (score: 4.73).
- Compressor relocation improves space for the operators (score: 4.87).

4. Conclusion

In this study a noise barrier has been developed to reduce noise generated by an air compressor in the assembly area of an Indonesian teak wood furniture manufacturing company called PT Jawa Furni Lestari. We used Pahl and Beitz approach for the barrier development process. As the main dampening materials, we used plywood, dampening carpet, glass wool, and apollo carpet.

The result of the study shows that the construction of the barrier could reduce noise by 33.29 dB, i.e. from 106.28 dB to 73.99 dB. In addition to reducing noise due to barrier construction, compressor relocation provides broader area for production activities. The evaluation result shows that the operators in the assembly area are very satisfied with the condition after the barrier is constructed. In terms of economic value, the total cost of the barrier construction was relatively cheap and acceptable for the company

Based on the evaluation result, we conclude that the barrier developed in this study can be used as an alternative way of reducing noise in the production area. The utilization of the idle space under the stairs will be beneficial to the company because it makes the barrier construction more efficient.

Nomenclature

$TL_{Overall}$	total noise (dB)
L_n	noise level at the n^{th} source (dB)
L_W	sound power level of noise sources (dB)
RPM	engine speed
MW	engine power
$TL_{barrier}$	barrier transmission loss (dB)
NR_{Plan}	noise to be reduced (dB)
A_{total}	total absorption area (dB)
St_{otal}	total barrier area (dB)
NR	noise reduction (dB)

References

[1] Safe Work Australia. Managing noise and preventing hearing loss at work. http://creativecommons.org/licenses/by-nc/3.0/au/; 2011. Accessed May 9, 2015.

[2] The Ministry of Environment of the Republic of Indonesia. The Decree of the Minister of Environment Number Kep-48/MENLH/11/1996 on the Standard noise level (in Indonesia); 1996.

[3] Freivalds A, Niebel BW. Niebel's Methods, standards, and work design. 12 ed. Europe: McGraw-Hill Education; 2008.

[4] Utama Q. Modul pelatihan noise control management. Bandung: ACET Service Indonesia; 2002.

[5] Mediastika CE. Akustika bangunan prinsip-prinsip dan penerapannya di Indonesia. Jakarta: Erlangga; 2005.

[6] The Ministry of Manpower of Republic of Indonesia. The Decree of the Minister of Manpower Number Kep-51/MEN/1999 on Threshold limit values for physical factors in the workplace (In Indonesia); 1999.

[7] Cross N. Engineering design methods: strategies for product design. 2nd ed. New York: John Wiley & Sons; 1994.

[8] Parkin PH, Humpeys HR, Cowell JR. Acoustics, noise and buildings. London: Faber & Faber; 1979.

[9] Mediastika CE. Material akustik pengendali kualitas bunyi pada bangunan. Yogyakarta: Andi Offset; 2009.

[10] Maekawa Z, Lord, P. Environmental and architectural acoustics. London: E & FN SPON; 1994.

[11] Canfeng Z, Shujie Y, Dong L. Comprehensive control of the noise occupational hazard in cement plant. Procedia Engineering 2012; 43(10):186-190.

[12] Barclay M, Kang J, Sharples S. Combining noise mapping and ventilation performance for non-domestic buildings in an urban area, building and environment. Building and Environment 2012; 52:68-76.

[13] Daigle GA. Effectiveness of noise barriers. Plenary lecture. 39th International Congress on Noise Control Engineering 2010 (INTER-NOISE 2010). www.noisenewsinternational.net. Accessed May 9, 2015.

[14] Everaert V, Progneaux A, Bouillard Ph. Simulation of sound wave propagation in presence of noise barrier by using the partition of the unity finite elements method : a comparison with analytical methods in 2d cases. International Conference on Noise and Vibration engineering 2010. https://www.isma-isaac.be/past/conf/isma2010/.../isma2010_0182.pdf. Accessed May 9, 2015.

[15] Satwiko P. Fisika bangunan 1. 1st ed. Yogyakarta: ANDI; 2009.

[16] Fitzsimmons J, Fitzsimmons M. Service management: Operations, strategy, and information technology. Boston; McGraw-Hill; 2004.